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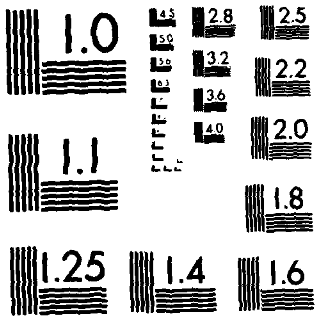

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US Army Corps of Engineers
Cold Regions Research & Engineering Laboratory

Frozen soil characteristics that affect land mine functioning

Paul W. Richmond

Prepared for
OFFICE OF THE CHIEF OF ENGINEERS

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This report discusses the results of an experiment to determine the effect of five factors on the load transferred through frozen soil to a buried land mine. The five variables examined were load, temperature, number of freeze-thaw cycles, soil, and water content. Analysis of a half-fraction factorial experiment shows that no one variable can be used as a predictor of mine functioning performance.

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PREFACE

This report was prepared by Paul W. Richmond, Mechanical Engineer, Applied Research Branch, Experimental Engineering Division, U.S. Army Cold Regions Research and Engineering Laboratory.

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FROZEN SOIL CHARACTERISTICS THAT AFFECT LAND MINE FUNCTIONING

Paul W. Richmond

INTRODUCTION

The Mine/Countermine Winter Warfare Workshop (Lunardini 1981) identified possible performance problems with land mines in a winter environment. One potential problem identified for further investigation was the effect of frozen soil on land mine performance. This study examines how several significant soil characteristics affect the load transferred through frozen soil to an antitank mine.

This study attempted to identify the most significant soil characteristics that affect the load transferred through a frozen layer of soil. A fractional factorial experiment was used in an attempt to identify which variables would have the most significance in a model of the load transfer process. Ideally this would allow estimates of minefield reliability, given a few characteristics of the frozen soil covering the mines.

BACKGROUND

During World War II land mines frozen in place did not function (Genseler 1973). The problem was also observed during the Korean War (Smith 1972). More recently, work at the Waterways Experiment Station (Womack 1958) showed that the operation of modern antitank mines (the M15 and M19) can be affected by frozen soil. Womack determined the optimum burial depth for the M15, and the experiments included tests in which the ground over the mines was frozen. Limited performance was observed in mines placed 200 mm deep. Results from mines in shallower emplacements were inconclusive, since the soil particles had not bonded together during freezing because of low water content.

Both the M15 and M19 mines rely on an applied force to depress a pressure plate for activation. The pressure plate of the M15 antitank mine is 17 mm in height and 190 mm in diameter. The mine requires a force of

1557 to 3336 N applied to the pressure plate for activation. The pressure plate of the M19 mine is 201 mm in diameter and requires a force of 1335 to 2224 N for activation.

Roark (1954) presents equations for calculating the maximum stress and deflection of a circular plate with fixed edges. The maximum stress occurs at the edge of the plate and is given as

$$s = \frac{3W}{4\pi A^2} \qquad (1)$$

W is the applied load and A is the thickness of the plate. The maximum deflection (y) occurs at the center of the plate:

$$y = \frac{3W\,(m^2-1)\,a^2}{16\pi\,E\,m^2\,A^3} \qquad (2)$$

where m is the reciprocal of Poisson's ratio, E is Young's modulus (tension), and a is the plate radius. According to Roark, five conditions must be met before using the equations:

a. The plate must be flat, of uniform thickness, and of a homogeneous isotropic material.

b. All forces - loads and reactions - must be normal to the plane of the plate.

c. The plate cannot be stressed beyond the elastic limit.

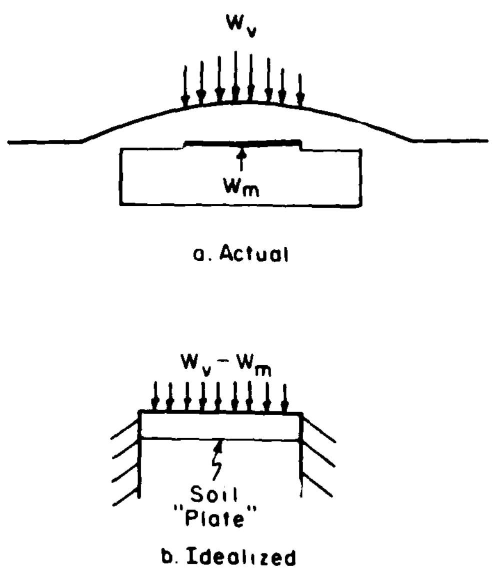

Figure 1. Actual and idealized loading of a soil/mine system.

d. The thickness cannot be more than about one quarter of the least transverse dimension, and the maximum deflection not more than about one half the thickness.

e. The boundary conditions must be appropriate.

The actual and idealized loading of a soil/mine system are shown in Figure 1. W_v and W_m represent the vehicle load and the resistance of the mine spring system, respectively.

To apply Roark's equations to a frozen soil "plate", an idealized case as depicted in Figure 1b was assumed and conditions a, b, and c were met. The soil was assumed to be elastic as long as the maximum stress did not reach the tensile strength of the frozen soil. Condition d holds if the

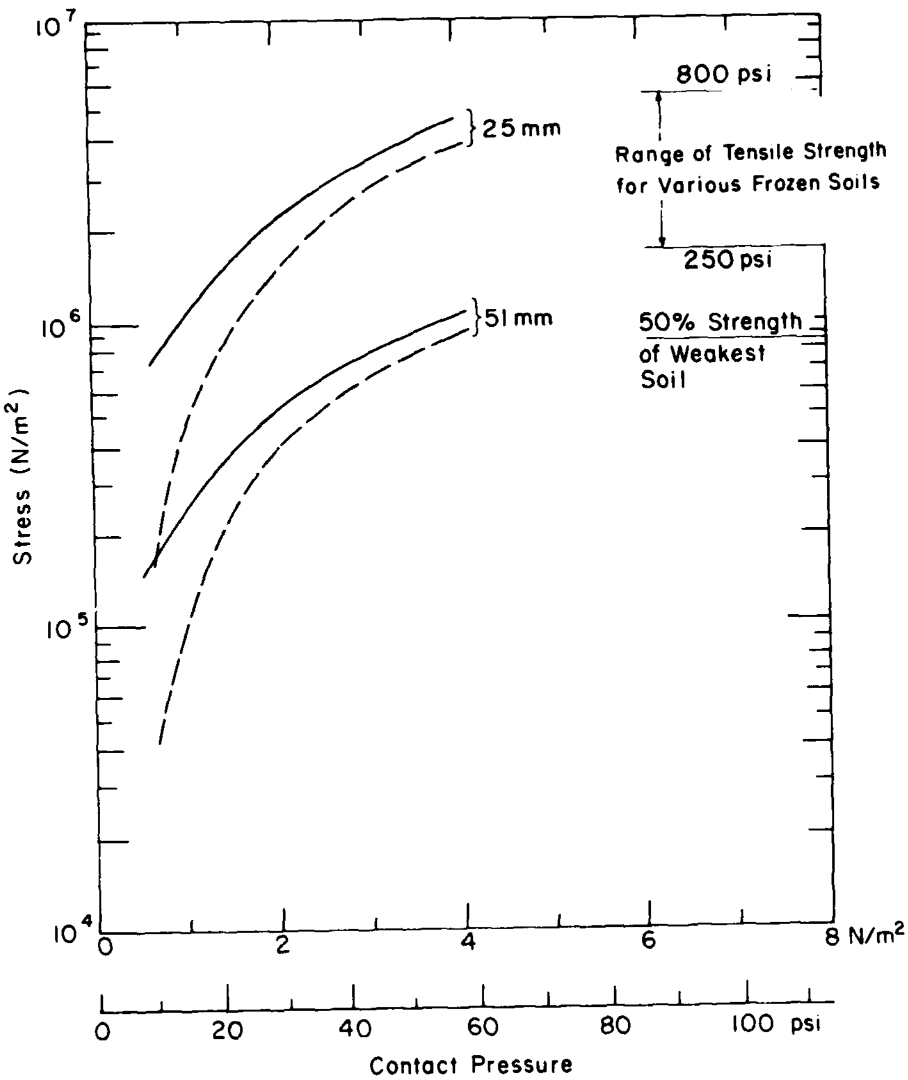

Figure 2. Maximum stress calculations, M15 mine.

soil thickness is less than 48 mm (the least transverse dimension; the plate diameter for the M15 mine is 190.5 mm). Since normal emplacement is 51 mm (2 inches) of soil over the mine, which is above the limit of applicability set by Roark, the stress was calculated for both 25 mm and 51 mm of soil thickness.

Equation 1 was used to calculate the curves in Figure 2. The solid curves were calculated by using only the vehicle contact pressure applied over the area of the pressure plate for the load term W. The dashed curves were obtained by subtracting 1557 N from the vehicle load to obtain W. These stresses are what would be expected just at activation of an M15 mine that had the minimum force requirement for activation. The stresses were calculated for soil thicknesses of 25 and 51 mm. For 25 mm of soil cover, the calculated applied stress is in the range of tensile strengths (Table 1 and Fig. 2). It was therefore concluded that the frozen soil would fail around the edge of the mine pressure plate, and the mine would activate with a cover of 25 mm. However, the standard method for emplacing these

Table 1. Characteristics of frozen soils.

Soil type	Temp. °C	Poisson's ratio	Young's modulus (N/m^2)	Tensile strength (N/m^2)	Source
Fairbanks silt	-10	-	1.0×10^{10}*	5.5×10^6	Haynes (1978)
Undisturbed Fairbanks silt	-10	.38	1.2×10^{10}	-	Stevens (1975)
Manchester fine sand	-3.9	-	2.1×10^{10}	3.26×10^6	Offensend (1966)
Manchester fine sand	-9.4	-	2.3×10^{10}	4.14×10^6	Offensend (1966)
Manchester fine sand	-17.8	-	6.4×10^{10}	4.4×10^6	Offensend (1966)
Fairbanks Silt	-3.9	-	1.4×10^{10}	1.7×10^6	Offensend (1966)
Fairbanks silt	-9.4	-	1.2×10^{10}	2.5×10^6	Offensend (1966)

* Initial tangent modulus

mines is to cover them with 50 mm of soil, and it does not appear that the mines would function in frozen soil with this amount of cover.

Equation 2 was used to calculate the maximum deflection at the center of the frozen soil plate. Results showed that the deflection would not be great enough to activate the mine.

From the discussion above it can be seen that the tensile strength of frozen soil and vehicle contact pressure determine the effectiveness of land mines buried in frozen soil. Soil tensile strength is dependent on a number of parameters, but only a small amount of data exists because of the difficulty of performing tensile strength tests on frozen soil. Therefore, an experiment was designed to examine the performance of land mines buried in frozen soil and the effects of various soil characteristics.

EXPERIMENTAL DESIGN

In a factorial experiment, several variables are controlled and the effect on the outcome is investigated at two or more levels of each variable.

For this experiment, four characteristics of frozen soil were selected as variables. A fifth variable, vehicle contact pressure, was also considered. The load applied by a vehicle and the load sensed by an emplaced mine were measured. For analysis the percent load transferred was considered the system response. The variables and levels selected are as follows:

1) Soil: sand or silt
2) Water content: sand 2.5%, 5%, silt 10%, 20%
3) Freeze/thaw cycles: 0 and 3 freeze/thaw cycles
4) Tire pressure (load): 179.3 kPa (26 psi) and 55.2 kPa (8 psi)
5) Temperature: -9°C and -4°C

The two levels of water content (W_c) were chosen as low and medium values for the two soils. The number of freeze/thaw cycles would affect the consolidation or density of the soil. Tire pressure was used as a measure of vehicle contact pressure. The temperatures were chosen to obtain high and low values of soil strength, other conditions being equal.

This design matrix yields 32 possible combinations to be tested. Only four of the 32 combinations could be tested at one time because of equipment constraints and the amount of time required to freeze the soil.

Variable

Test Run Combinations	1	2	3	4	5
	−	−	−	−	+
	+	−	−	−	−
	−	+	−	−	−
	+	+	−	−	+
	−	−	+	−	−
	+	−	+	−	+
	−	+	+	−	+
	+	+	+	−	−
	−	−	−	+	−
	+	−	−	+	+
	−	+	−	+	+
	+	+	−	+	−
	−	−	+	+	+
	+	−	+	+	−
	−	+	+	+	−
	+	+	+	+	+

where:

Variable	Level +	Level −
1 Soil	Sand	Silt
2 Water content	Medium	Low
3 Freeze/thaw cycles	3	0
4 Load	179 kPa	55.2 kPa
5 Temperature	−4°C	−9°C

Figure 3. Half-fraction of a 2^5 factorial matrix, each variable at two levels.

Table 2. Test combinations for half-fraction experiment.

Sample number	Transducer	Mine	Soil	Water content (%)	Number of freeze/thaw cycles	Tire inflation pressure (kPa)	Temp. (°C)
1-1	327	B	Sand	2.5	0	55.2	-9
1-2	201	D	Sand	5	0	179.3	-9
1-3	202	C	Silt	10	0	179.3	-9
1-4	200	A	Silt	20	0	55.2	-9
2-1	200	D	Silt	10	0	55.2	-4
2-2	202	B	Sand	2.5	0	179.3	-4
2-3	201	C	Silt	20	0	179.3	-4
2-4	327	A	Sand	5	0	55.2	-4
3-1	201	C	Sand	2.5	3	179.3	-9
3-2	327	D	Sand	5	3	55.2	-9
3-3	202	B	Silt	20	3	179.3	-9
3-4	200	A	Silt	10	3	55.2	-9
4-1	202	A	Silt	10	3	179.3	-4
4-2	201	C	Silt	20	3	55.2	-4
4-3	200	B	Sand	2.5	3	55.2	-4
4-4	327	D	Sand	5	3	179.3	-4

Therefore, it was decided to conduct a half fraction (that is, 16) of the full factorial experiment, as shown in Figure 3. Each level was assigned a + or - sign. The resulting test combinations and randomized performance sequence are shown in Table 2.

TEST PROCEDURE

Four wooden boxes (571 mm square x 140 mm deep) were lined with polyurethane plastic sheets and placed in the ground. The instrumentation, mines, and soil were placed in these boxes. The test samples were prepared by placing an M12 practice mine fuzed with an M604 practice fuze in the box. A hydraulic load cell, thermocouples, and wood cover were installed as shown in Figure 4. The assembled instrumentation is shown in Figure 5. The two soils selected for the test were a silt from Manchester, New Hampshire, and a local sand. Grain size distribution curves for these soils are given in Figure 6. After adjusting the water contents of the soils for each experiment, the soils were shovelled loosely into the boxes, covering the mines to a depth of approximately 50 mm. The soil was compacted a minimal amount while leveling. The test boxes were then covered with a plastic sheet and three freezing panels (3.7 m x 0.46 m each). An ethylene glycol coolant solution at approximately -10°C was pumped through the panels to freeze the soil. The panels were covered with a plastic sheet; a trench was dug around the panels to keep rain water from running into the sample boxes.

The temperature in the boxes was monitored. When the temperature at thermocouple position 1 (Fig. 4) was below 0°C, the temperature of the coolant was raised so the temperature at location 2 would reach the desired test temperature (-4°C or -9°C). This was done to stabilize the temperature as much as possible. For tests that were to have three freeze/thaw

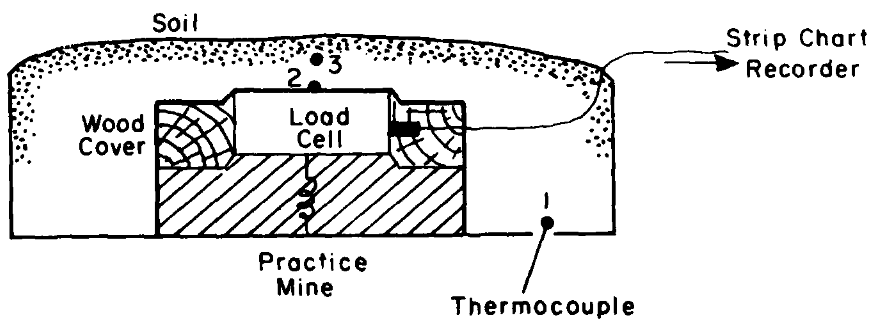

Figure 4. Schematic of instrumentation (thermocouples located at points 1, 2, and 3).

Figure 5. Assembled instrumentation.

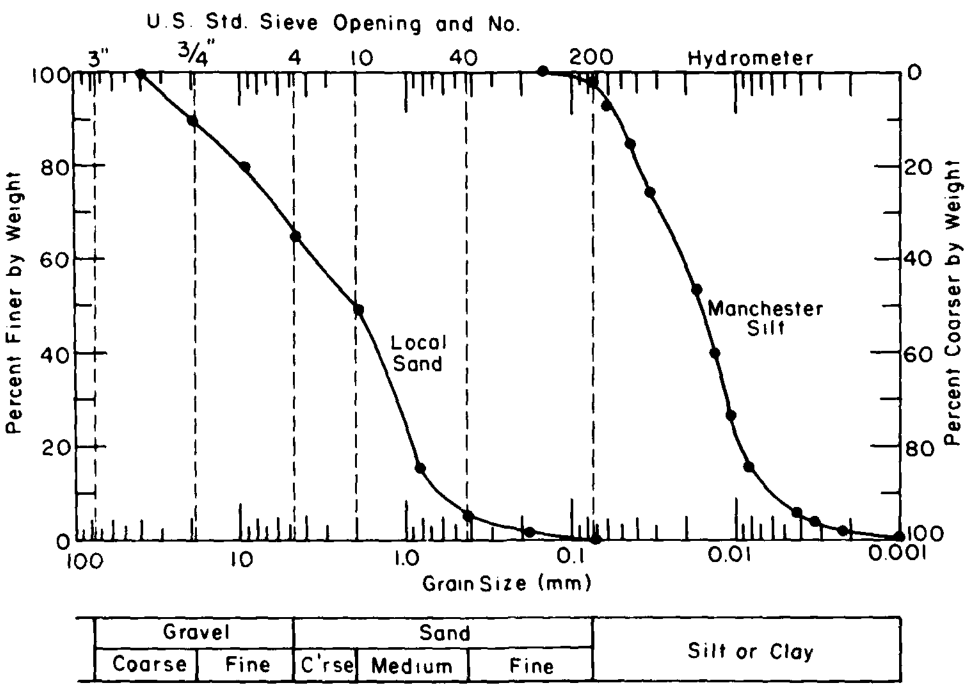

Figure 6. Soil gradation curves.

cycles, the temperature at location 2 was cycled between -12°C (maximum) and 4°C (minimum) three times; the temperature at location 1 was then brought down to approximately 0°C.

The freezing panels and plastic covers were then removed and the CRREL instrumental vehicle (CIV) (Blaisdell 1982) was driven over each test box so that the right front tire rolled over the center of the box. The CIV was driven over the test box, then backed up over it, and then moved forward to stop in the center of the box. The tire had been inflated to the test pressure (179.3 or 55.2 kPa). The average vertical force on the right front wheel was measured as it moved over the test box. The mine load cell output during loading was recorded on a strip chart recorder. Each box was tested in turn.

After each box was tested, thermocouple readings were taken. Soil samples at the surface of each box were taken for water content analysis.

RESULTS AND ANALYSIS

The results of each test are shown in Table 3. The data are presented in ascending order of the percent load transfer (first-pass load divided by the vehicle load). The table also shows the test conditions, measured water content, and soil temperature data recorded during the tests. A number of tests were repeated because of equipment problems that allowed the soil to thaw.

Variation in test temperatures occurred for two reasons. First, there was uneven freezing under the panels, most likely due to incomplete contact between the ground and the freezing panels. Secondly, the test boxes warmed while the tests were being conducted. The third thermocouple was added to obtain additional temperature data, which showed that in some cases there was a temperature variation of approximately 2°C in the top 50 mm of the soil. It is believed that these variations did not have an effect on the analysis of the data, since the average temperature (thermocouples 2 and 3) was close to the desired test temperature. In addition, the temperature difference between the two levels was large enough to observe differences in soil strength.

Measurements made after the tests showed some change from the desired water content. In most cases these variations were small and can be attributed to moisture migration during freezing.

Table 3. Test conditions and results.

Test no.	Date 1981	Soil	Wc (%)	Thaw cycles	Tire press. (kPa)	Temp. (°C)	Wc (%)	Temperature °C 1	Temperature °C 2	Temperature °C 3	Vehicle load (N)	Load on mine, N 1	Load on mine, N 2	Load on mine, N 3	Load on mine, N 4	Response Load trans. (%)	Remarks
2B-4*	22 Oct	sand	5	0	55.2	-4	6.1	-1.0	-1.6	-2.8	5502.4	511.5	511.5	600.5	-	9.3	Did not function
3A-3	19 Nov	silt	20	3	179.3	-9	26.8	-4.0	-12.0	-9.7	6129.6	800.7	978.6	1556.9	-	13.1	Did not function
4-2	6 Oct	silt	20	3	55.2	-4	25.3	-1.9	-4.6	-1.2	6776.4	889.6	622.7	578.3	-	13.1	Did not function
3-3	2 Sep	silt	20	3	179.3	-9	28.7	-5.7	-12.5	-10.3	6423.2	845.2	889.6	1023.1	-	13.2	Did not function
2-4	9 Jul	sand	5	0	55.2	-4	3.3	2.7	4.9	-	5210.2	733.9	667.2	600.5	845.2	14.1	Funct. on 4th pass, tire inflation at 179.3 kPa, soil thawed.
2A-3	27 Jul	silt	20	0	179.3	-4	25.4	-1.8	-9.1	-	6449.9	978.6	1201.0	1868.2	-	15.2	Funct. on 3rd pass
2A-4	27 Jul	sand	5	0	55.2	-4	4.6	0	-3.9	-	5248.9	854.1	938.6	979.0	1254.5	16.3	No funct., part. thawed
1-1	10 Jun	sand	2.5	0	55.2	-9	9.5	3.3	-7.1	-	7287.9	1445.7	1623.6	1535.0	-	19.8	No function
2-2	9 Jul	sand	2.5	0	179.3	-4	2.6	1.0	5.8	-	6727.9	1467.9	2224.1	2313.1	-	21.8	Funct. 1st pass, thawed
3-1	2 Sep	sand	2.5	3	179.3	-9	3.2	-0.9	-9.1	-5.6	7023.7	1556.9	1690.3	1712.6	-	22.2	Funct. 3rd pass, thawed
1-2	10 Jun	sand	5	0	179.3	-9	3.4	-1.0	-7.6	-	7381.3	1645.8	2535.5	2491.0	-	22.3	Funct. 2nd pass, thawed
1-4	10 Jun	silt	20	0	55.2	-9	26.7	-1.3	-7.3	-	5828.9	1401.2	1467.9	1467.9	-	24.0	Did not function
2A-1	27 Jul	silt	10	0	55.2	-4	13.4	1.6	-5.7	-	6957.0	1823.8	2046.2	2713.4	4314.8	26.2	Functioned on 1st pass
2B-1	22 Oct	silt	10	0	55.2	-4	10.0	0	-4.1	-3.4	6969.9	1912.7	1823.8	3247.2	-	27.4	Functioned on 1st pass
4-3	6 Oct	sand	2.5	3	55.2	-4	3.9	-1.8	-5.3	-4.4	6117.6	1823.8	2135.1	2224.1	-	29.8	Did not function
2-1	9 Jul	silt	10	0	55.2	-4	10.8	10.4	2.5	-	6727.9	2179.6	2402.0	2668.9	-	32.4	Funct. 1st pass, thawed
3A-1	19 Nov	sand	2.5	3	179.3	-9	2.9	-2.3	-9.3	-9.7	7295.0	2491.0	2802.4	3558.6	-	34.1	Did not function
3-4	2 Sep	silt	10	3	55.2	-9	9.2	-1.9	-10.4	-8.4	5426.8	1957.2	2046.4	1912.7	-	36.1	Functioned on 1st pass
2B-3	22 Oct	silt	20	0	179.3	-4	21.6	-0.7	-4.6	-2.4	6120.7	2224.1	3133.7	3869.9	-	36.3	Functioned on 3rd pass
3A-4	19 Nov	silt	10	3	55.2	-9	13.2	-2.8	-10.1	-9.0	5346.7	2179.6	2224.1	2046.2	-	40.8	Functioned on 1st pass
1-3	10 Jun	silt	10	0	179.3	-9	11.1	0.1	-7.9	-	6703.4	2891.3	3202.7	2224.1	-	43.1	Functioned on 1st pass
2A-2	27 Jul	sand	2.5	0	179.3	-4	4.3	1.0	-6.2	-	7059.3	3380.6	3781.0	3514.1	-	47.9	Mine wasn't armed, thawed
3A-2	19 Nov	sand	5	3	55.2	-9	4.5	-3.7	-10.9	-10.9	6716.8	3869.9	3869.9	3869.9	-	54.3	Did not function
2B-2	22 Oct	sand	2.5	0	179.3	-4	3.0	-0.4	-3.8	-3.6	6816.4	4136.8	4670.6	4893.0	-	60.7	Functioned on 1st pass
4-1	6 Oct	silt	10	3	179.3	-4	10.1	0.4	-4.6	-2.4	7097.1	4626.1	4804.1	4715.1	-	65.2	Functioned on 1st pass
4-4	6 Oct	sand	5	3	179.3	-4	5.6	-1.6	-4.6	-3.8	5770.6	3958.9	4003.4	4047.9	-	68.6	Did not function

*The letter A or B was added to the test number to indicate that this was the second (A) or third (B) run of this configuration. These repetitions were required to obtain a complete set of data. (No data were collected for tests 2-3 and 3-2.)

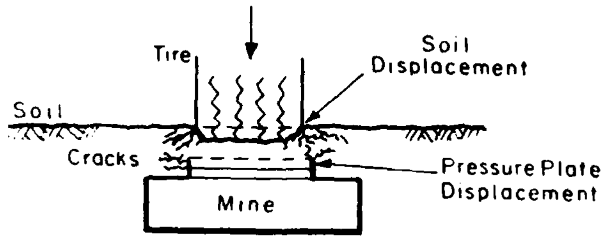

Figure 7. Possible method of load transfer and plate deflection.

When the freezing panels and polyethylene sheet were removed, the soil was observed to be level with the box rim. This was most likely caused by the weight of the panels. It had the effect of reducing the soil cover from 50 mm to 30 mm. It was also observed that the soil particles of the low-water-content (10%) silt did not bond together significantly and hence did not produce a hard frozen layer. As would be expected, higher loads in general were transferred through this soil.

In all tests, some load was measured at the pressure plate surface; however, only in the thawed or low-water-content silt tests were soil compaction and fracturing observed. A postulated mechanism of load transfer and simultaneous deflection of the pressure plate is illustrated in Figure 7. The expected deflection of the plate was 6 to 10 mm at activation. If cracks occurred, as indicated in Figure 7, the soil would be forced to rebound by the pressure plate as the load was removed, with the outward appearance of little or no disturbance, as observed during the tests.

Table 3 also presents the results of the mine functioning performance. The M12 mine requires between 1739 and 3287 N to function, as indicated by the two double lines in Table 3 (based on first pass loading). One fuze functioned below the range and two did not function above. The reason why these failed to meet the specifications could not be determined. In general, it can be said that most of the mine non-functions occurred in the higher water content soils. It is also noted that in some cases, although rarely, the mine functioned during subsequent loadings.

Variations in the load applied by the vehicle were due to the uneven terrain at the test site, which caused the vehicle center of gravity to be shifted, hence shifting the weight on each wheel. For the tests discussed in the factorial analysis below, the average contact pressure was 132.4 and 238.5 kPa (standard deviations 15.2 and 21.4) for tire inflation pressures

Table 4. Estimated effects.

Test no.	Response $Y_{f(\%)}$	Response $Y_{p(\%)}$	Effects* Using the Y_f response		Using the Y_p response	
1-1	19.8	43.6	Avg (0)	34.7	Avg (0)	57.5
1-2	22.3	28.7	123	21.5	123	35.2
1-3	43.1	55.6	Load (4)	15.5	12	20.8
1-4	24.0	52.8	12	12.7	f/t** (3)	18.7
2B-1	26.8	59.0	W_c† (2)	-10.2	13	18.7
2B-2	60.7	78.2	f/t (3)	9.6	W_c (2)	-13.6
2B-3	36.3	46.8	13	8.9	34	-11.9
2B-4	9.3	20.5	Temp (5)	7.2	134	-11.1
3A-1	34.1	44.0	24	-6.5	23	8.3
3A-2	54.3	119.4	23	5.6	Soil (1)	7.9
3A-3	13.1	16.9	Soil (1)	5.3	24	-5.8
3A-4	38.4	84.5	134	-4.8	Temp (5)	3.6
4-1	65.2	83.9	34	-4.1	Load (4)	-3.5
4-2	13.1	28.9	14	2.7	124	-2.3
4-3	29.8	65.6	234	2.3	14	1.9
4-4	71.3	91.8	124	2.0	234	1.4

* Each effect is identified by a set of integers corresponding to each variable at the + level; these integers also correspond to the subscripts of the B variable in eq 3.

** f/t = freeze/thaw

† W_c = water content

of 55.2 and 179.3 kPa respectively. The effect of this variation in tire contact pressure was thought to be minimal, however, since a further check on the analysis, Y_p, was calculated.

The data used for the factorial analysis are shown in Table 4. The response Y_f was obtained by dividing the mine load cell output by the vehicle load cell output, thus obtaining the percentage of the load transferred to the mine. The response Y_p was obtained by first dividing the vehicle output by the contact area of the tire (279.4 or 476.8 cm^2 for tire pressures of 179.3 and 55.2 kPa respectively). This value was then multiplied by the area of tire that would be in contact with the load cell if it were not covered with soil (216.8 cm^2) and the load cell output was divided by this "corrected" load value. It was assumed that this value would be more representative of the loading described in Figure 1. Note that Y_f obtained for test 3A-2 is 119.4%, which indicates that some other mechanism of load transfer occurred. Two possible explanations for this high value are that the pressure distribution under the tire was not uniform or that a larger piece of gravel caused a direct transfer of load through the soil to the load cell.

The estimated effects of each variable (Table 4), obtained by using Yate's algorithm (Box 1978), are presented in decreasing order. These effects when divided in half can be used as coefficients to eq 3:

$$Y = B_0 + \sum_{i}^{K} B_i X_i + \sum_{i>1}^{K} B_{ij} X_i X_j + \sum_{i>j>1}^{K} B_{ijl} X_i X_j X_l \ldots \quad (3)$$

where B = coefficient = Effect/2

X_i = level (+ or -) of variable i

K = number of variables.

It can be seen that the larger the effect, the greater its influence on the response (Y) for a given condition. The effects were calculated from the two sets of response data (Y_f and Y_p) for the first pass data as described above. The major difference is that the pressure response (Y_p) data minimize the effect of the load variable. For this reason further analysis will consider only the force response.

The largest effect is the interaction of soil, water content, and freeze/thaw (123) which, because only a half-fraction experiment was performed, is confounded with the interaction of load and temperature (45), making interpretation of this information difficult. Figure 8 is a graphic representation of the data at each condition of the experiment. The cubes in this figure display the data related to the 123 interaction at the various levels of load and temperature. The values in the center of each cube are the average Y_f for that condition of load and temperature. It appears in general that the sand with three freeze/thaw cycles allows the greatest load transfer, although it was observed during the test that the low water content silt was not completely bonded. It had been thought that this would allow the greatest load transfer. The results may be explained by the presence of larger gravel in the sand, causing a weaker soil around the plate edge, or possible direct load transfer from the tire to the mine surface if a larger stone was present.

Replicates of three runs were obtained in the process of conducting the experiment; the individual run variances are shown in Table 5. The variability of each effect can be obtained by the equation

$$V(\text{effect}) = \frac{4}{N}\,\sigma^2$$

where N is the number of runs (16) and σ^2 can be estimated by the run variance, if a complete replicate is run.

Factorial analysis of the second and third passes over the mines did not produce significantly different values for the effects.

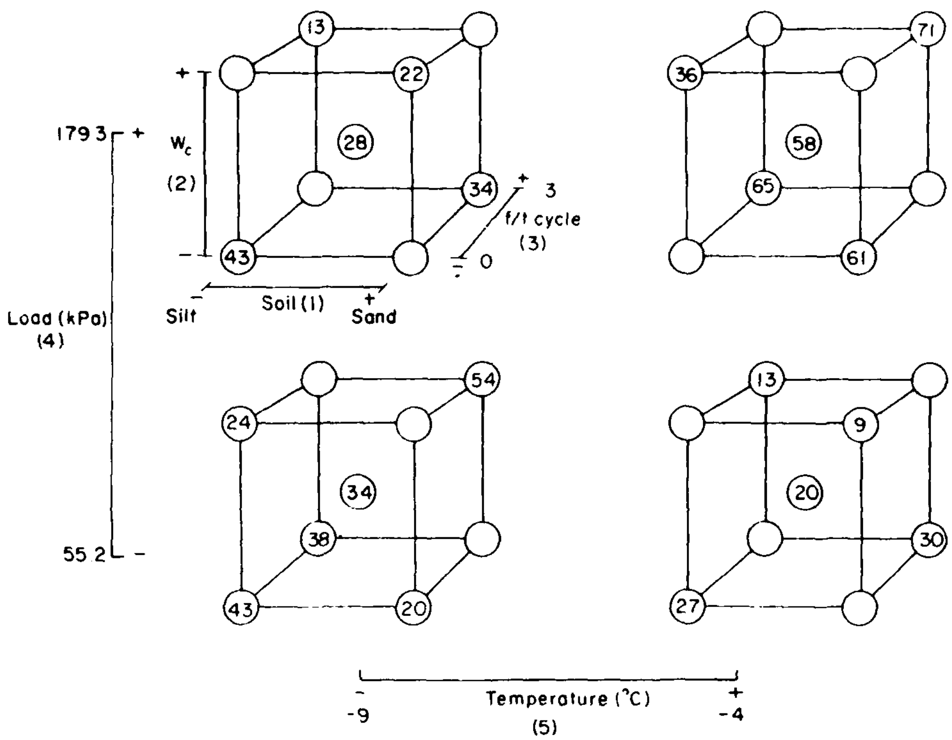

Figure 8. Graphical representation of data.

Table 5. Replicates of test runs.

Test no.	Response	Difference	Estimated variance S^2_i = (difference^2)/2
2B-1	27.4%		
2A-1	26.2	1.2	1.037
3-3	13.2		
3A-3	13.1	0.1	0.005
3-4	36.1		
3A-4	40.8	4.7	11.045

Table 6. Estimated effects with constant load.

179.3 kPa		55.2 kPa	
Avg (0)*	42.5	Avg (0)*	27.4
Temp (3)	28.7	Temp (3)	-15.1
W_c** (2)	-16.6	f/t† (4)	-14.6
12	14.6	23	-14.5
Soil (1)	7.9	12	11.5
13	7.9	13	-4.1
f/t (4)	5.5	Soil (1)	3.4
23	4.2	W_c(2)	-2.9

*Each effect is identified by a set of integers corresponding to each variable at the + level; these integers also correspond to the subscripts of the B variable in eq 3.
**W_c = water content
†f/t = freeze/thaw

There is enough experimental data that they can be analyzed as two groups of data, each with one of the five variables held at either the + or - level. Table 6 shows the effects calculated with the load held at the + and - levels. In half factorials of this size (2^{4-1}), confounding occurs between the main effects (temperature, freeze/thaw, soil, load, water content) and the three-factor interactions. Two-factor interactions are confounded with other two-factor interactions. This analysis indicates that for high loads, temperature and water content have the most effect on the response; for smaller loads, temperature and freeze/thaw cycles have the greatest effect.

Figure 9 presents graphs of load transfer versus temperature for the two tire pressures. The dashed lines connect data collected under similar conditions, with the exception of the number of freeze/thaw cycles as indicated. In general, the load transferred increases with increasing temperatures, with the exception of three test conditions shown in Figure 9. Test 3A-2 was discussed earlier where it was postulated that this high load transfer value could be due to large gravel affecting the strength of

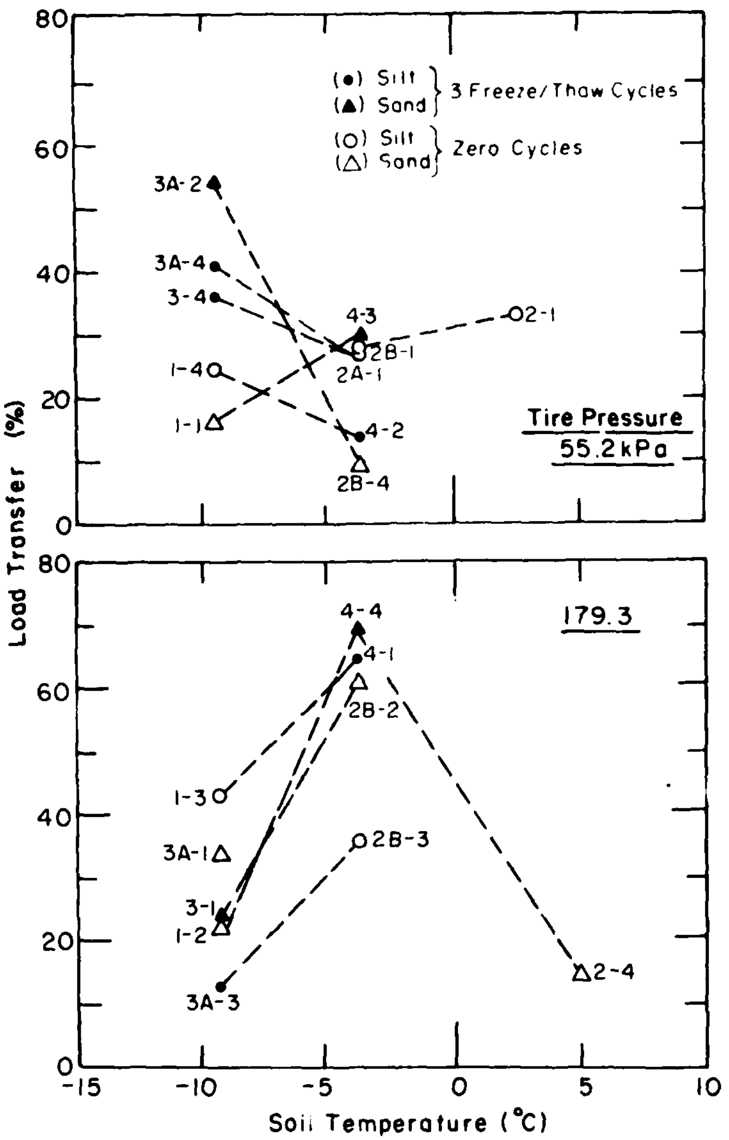

Figure 9. Graphs of load transfer vs temperature.

the sand over the mine. In addition, test 2-4 appears out of place, possibly due to remaining frozen soil or lack of large stones in the sand above the mine.

Further analysis, holding other variables constant, did not yield any additional information.

At this point it may be worthwhile to review the purpose of a half-fraction factorial experiment. Factorial experiments are used to model a process when there is a large number of variables and data are difficult to obtain. The half-fraction allows the experimenter to zero in on the variables that are most important, and then conduct further experiments if necessary with a limited number of variables (and trials) to complete the process model. The results of this experiment suggest that all of the variables have a significant effect on the process of load transfer from a wheel to a mine buried in frozen soil.

CONCLUSION

The results show that pressure mines buried in frozen soil may not function, depending on soil conditions.

The results of the analysis indicate that all of the variables considered affect land mine functioning in frozen soil, so it is not possible to make any general statement about when a mine will or will not function when buried in frozen soil.

RECOMMENDATIONS

1. Further work is needed to determine actual load transfer and displacement mechanisms in frozen soil.

2. Mine functions in frozen soil under tracked vehicles should be examined.

3. The effect of large particles embedded in the soil on land mine functioning needs to be investigated further.

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